



# ***Turbulence Lidar Development Status***

## **Weather Accident Prevention (WxAP) Annual Project Review**

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Coherent Technologies, Inc.

Cleveland, OH, Hilton South  
June 5-7, 2001

# Overview



## **Aviation Safety Program**

- **Background information**
- **Technical accomplishments to date**
  - ground and flight test activities
- **Plans**
  - flight test activities
  - algorithm development and performance simulation

# Overview



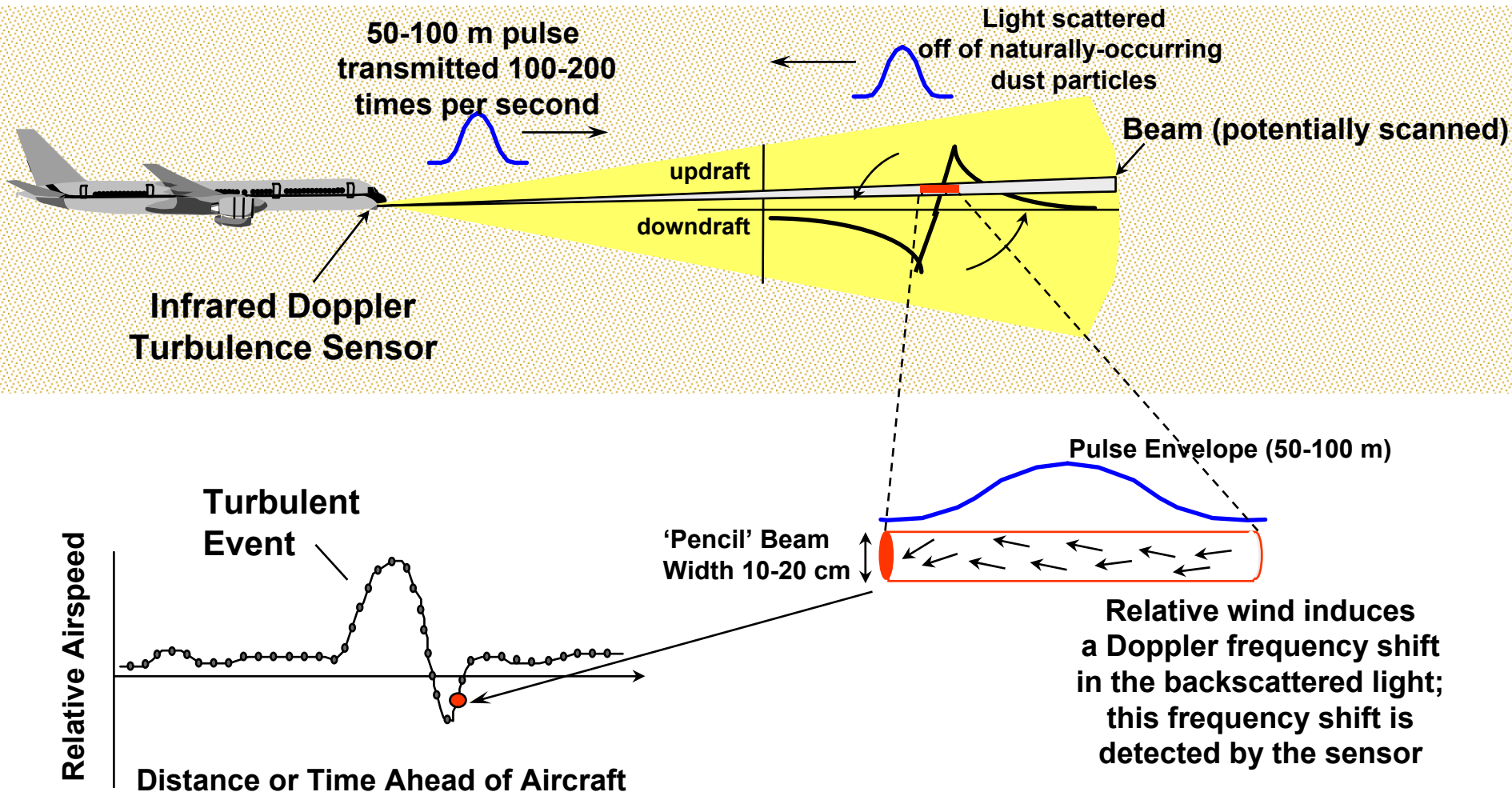
## Aviation Safety Program

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# General Principle of Infrared Doppler Radar (Lidar) Turbulence Measurement



Aviation Safety Program



# Turbulence Product Development Team Objective



## Aviation Safety Program

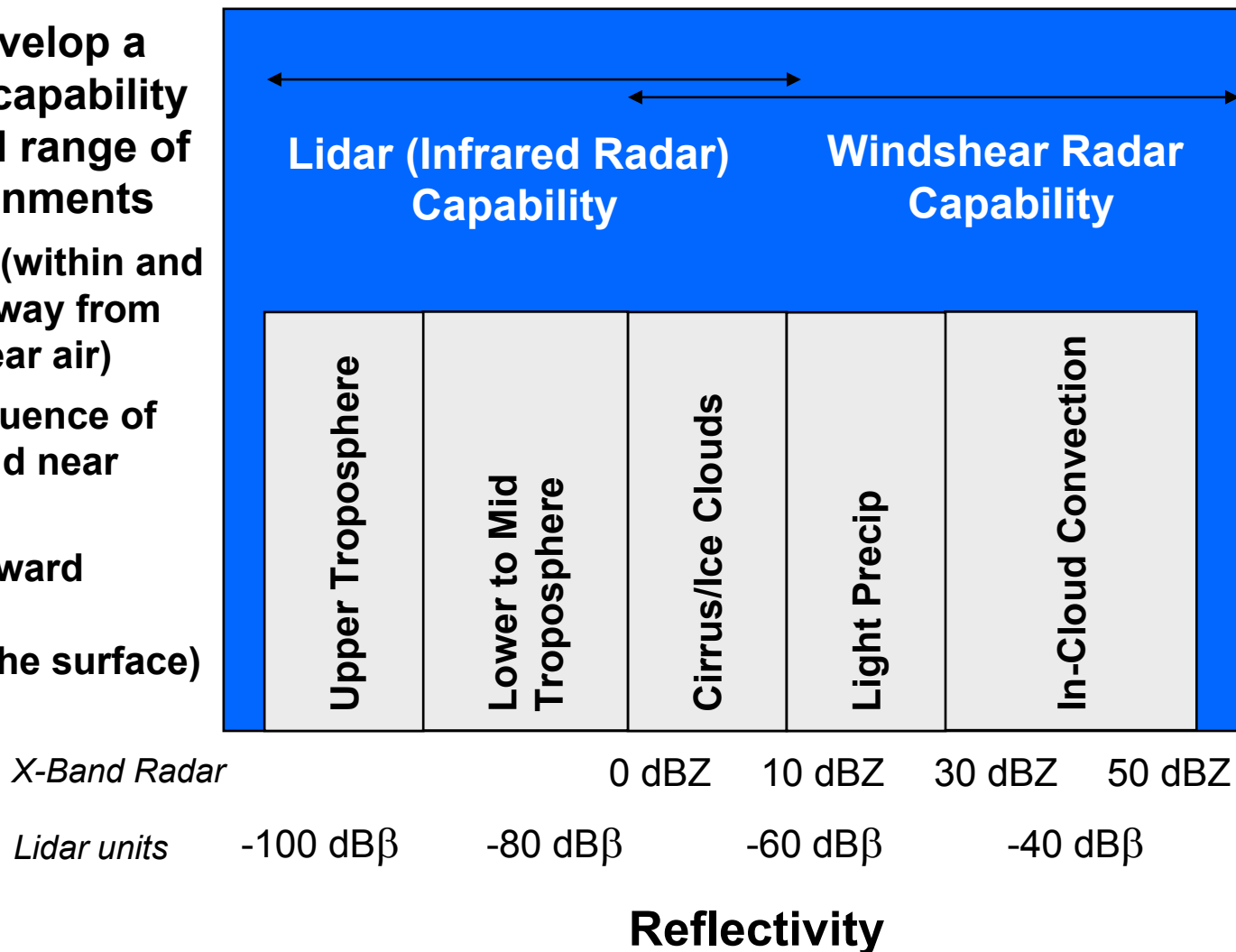
- **Develop a robust detection capability that spans the full range of turbulence environments**
  - **Provide Timely Reliable Tactical Warning to:**
    - Deviate,
    - Institute Cabin Safety Measures, and/or
    - Institute Mitigation Measures
  - **Provide Real-Time Alerts to AWIN Network**

# Complete Detection Capability Provided through Dual Wavelength Radar



**Aviation Safety Program**

- TDAM Objective:** Develop a robust detection capability that spans the full range of turbulence environments
- Convective Storms (within and as far as 40 miles away from visible clouds in clear air)
  - Jet Stream (at confluence of multiple streams and near boundaries)
  - Mountain Wave (upward propagating from disturbances near the surface)



# Technology Readiness Development Needs



## Aviation Safety Program

- **Lidar needs are similar to those for microwave radar and include:**
  - definition and characterization of hazard
  - hazard algorithm for quantifying the threat
  - validated algorithm(s) for using the IR radar to detect, discriminate, and quantify the threat
  - simulation test case development
  - validated system performance with properly designed field tests

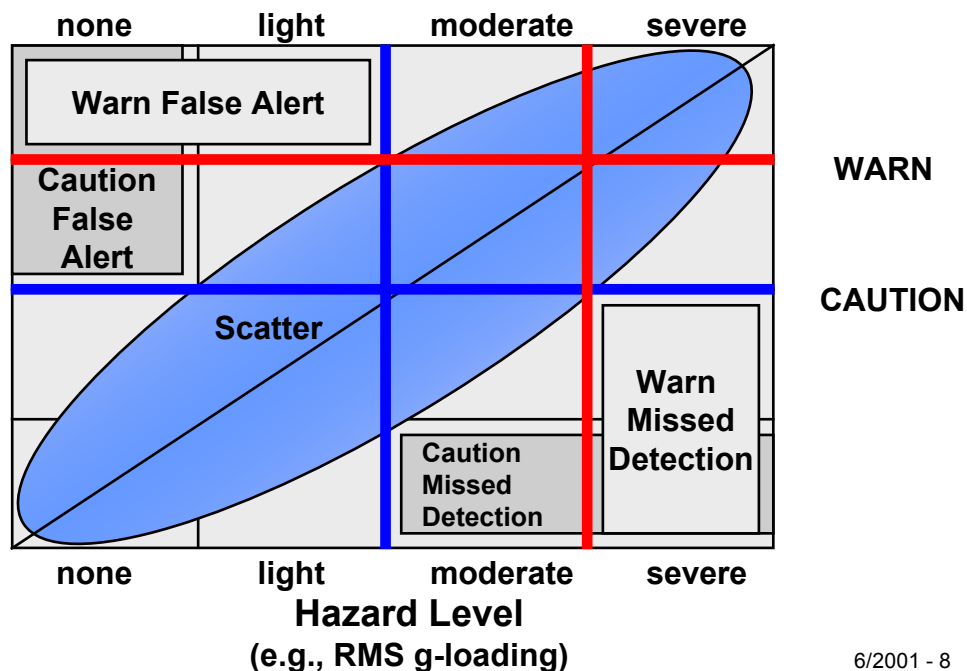
# Detection Issues



## Aviation Safety Program

- **Detection/False Alert must consider the random nature of turbulence**
  - multiple turbulence warning levels
  - multiple turbulence classes/types
  - viewing longitudinal velocity behavior and inferring the vertical
- **Definition of errors required (not just Type I and Type II)**
  - common issue for radar/lidar
  - must minimize scatter

Lidar Observable  
(Velocity Structure Function  
or Spectral Width)





# Flight Testing: Objectives and Needs



## Aviation Safety Program

- **More flight hours at cruise altitudes**
  - identified as a major gap
  - measuring turbulence levels requires a large number of flight hours
- **More flight hours in moderate or stronger turbulence**
  - mid-level altitudes with focus on convective (storm) and breaking wave turbulence
  - performance envelope for onboard radar and lidar
- **Extended data sets for aerosol/turbulence correlation modeling**
- **Scanning versus single line of sight configuration**
  - scanning will enable better characterization of turbulent events
    - more direct comparison with radar for joint tests
  - include a mixture of both modes

# Program Assets and Resources: Government Agency and Industry



## Aviation Safety Program

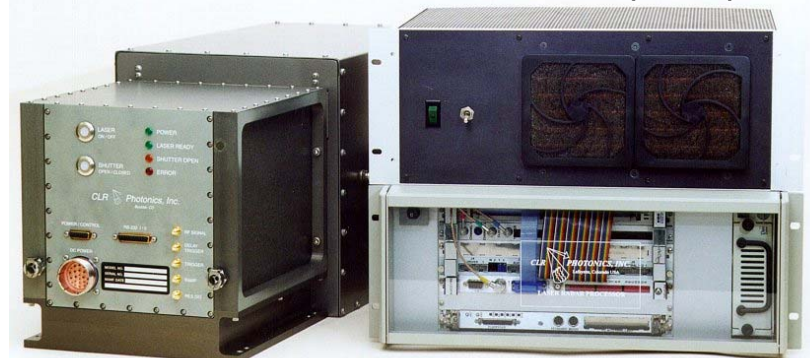
AFRL System for Precision Air Drop



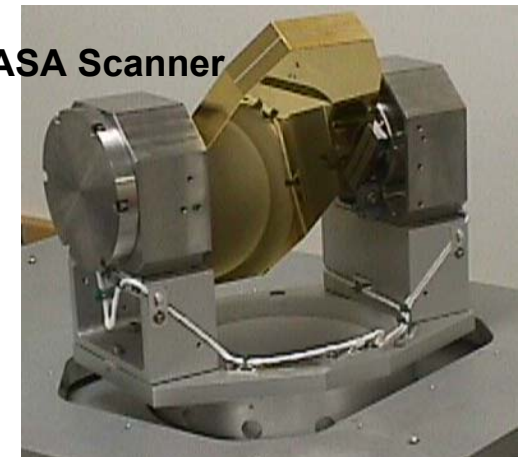
NASA/ACLAIM System



CTI/ARO MAG-1 Transceiver (future)



NASA Scanner



# Overview



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- **Background information**
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- **Plans**
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  - algorithm development and performance simulation

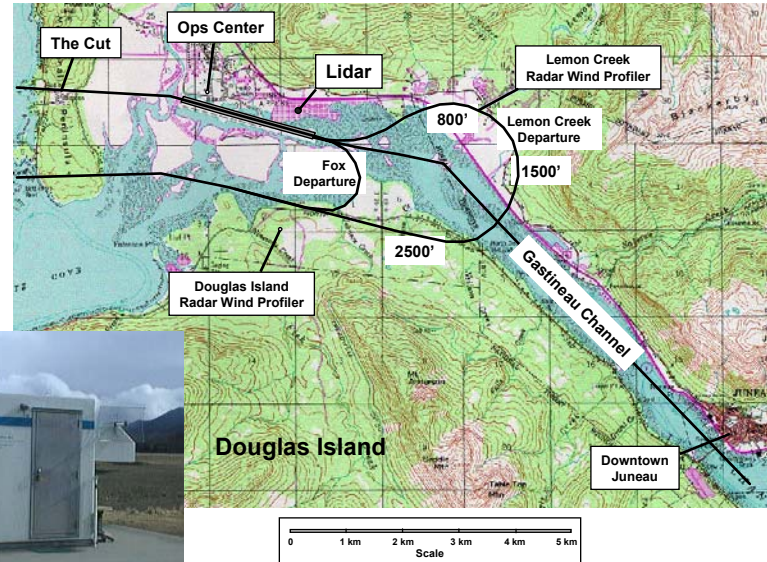
# TDAM 1998 Accomplishments: Lidar



## Aviation Safety Program

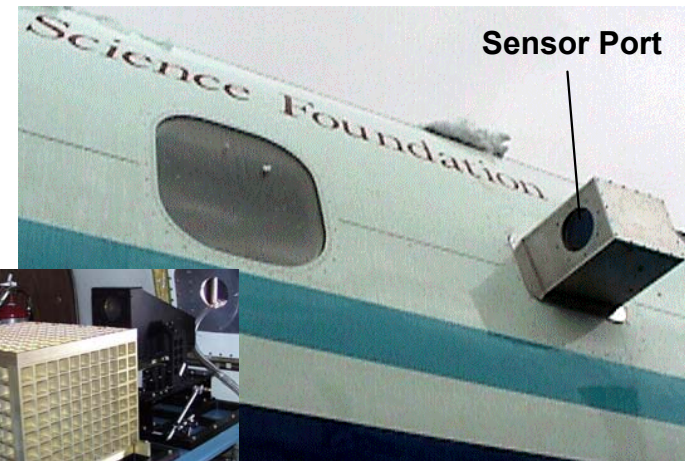
- **Juneau lidar deployment**

- characterization of low altitude wind shear and turbulence
- generated validated data sets to support development of lidar turbulence and wind shear detection algorithms



- **ACLAIM/Electra flights**

- Detected light to moderate turbulence at ranges between 3 and 6 miles ahead
- Penetrated turbulence to verify
- Operated 15 hours in a variety of conditions from ground to 25kft

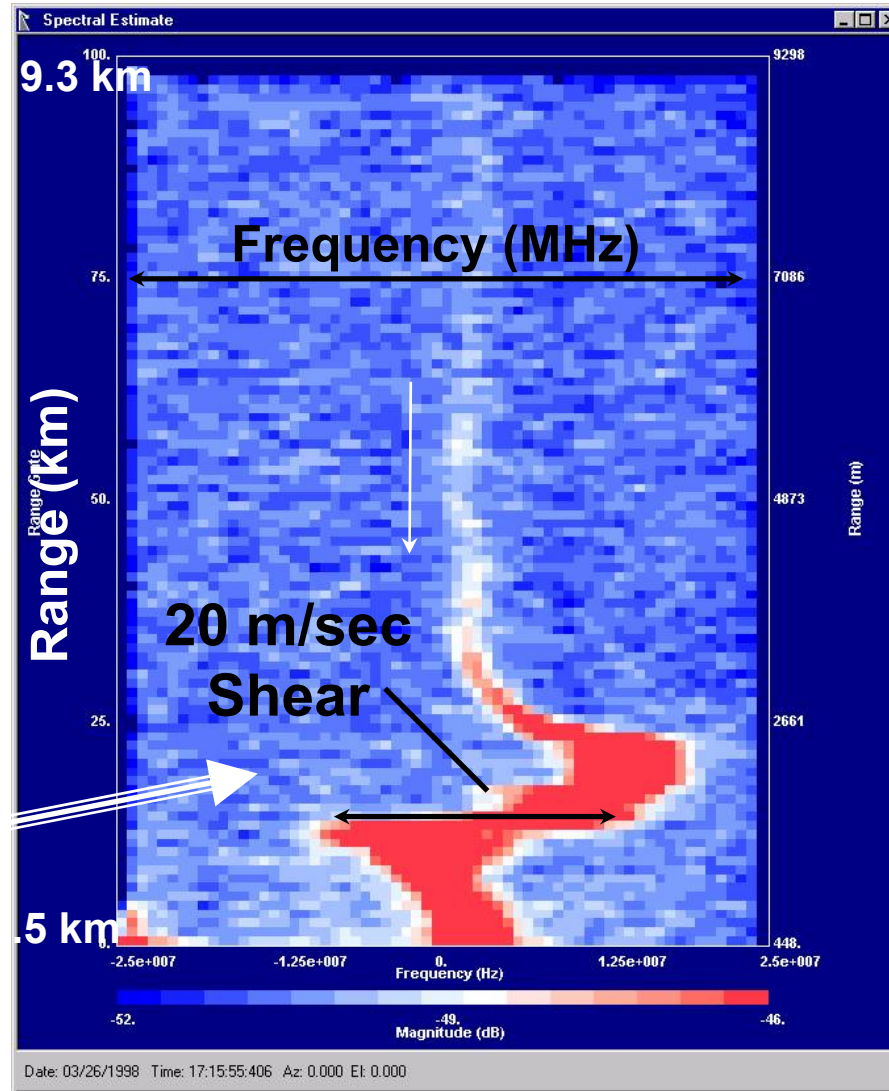
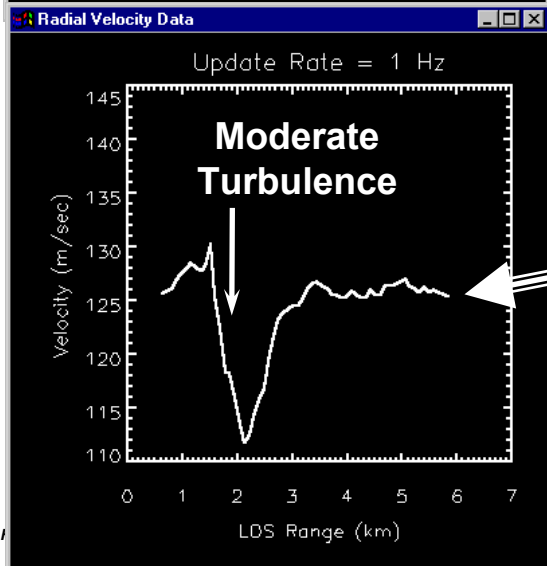
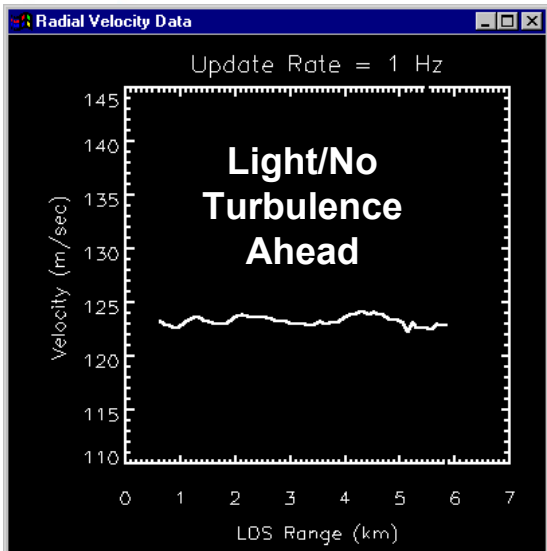




# Sample Doppler Spectrum from ACLAIM/Electra



**Aviation Safety Program**



# B-720 Compact Lidar Flight Tests



## Aviation Safety Program

- Collected lidar data to demonstrate CAT IR product capability at cruise altitudes
  - data consistent with performance model predictions
  - justified parametric system scaling for compact next-generation system
- Flights aboard Honeywell-owned B-720
- Conducted October, 2000
  - focus on cruise altitude operation
  - no significant turbulence encountered



# Overview



## Aviation Safety Program

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  - flight test activities
  - algorithm development and performance simulation

# FY01/02 Lidar Flight Tests



## Aviation Safety Program

- **DC-8 flight tests**

- lidar operates in a piggy-back fashion
- joint data for post-flight correlation with
  - in-situ
  - aerosol particle measurements
- support lidar performance scaling and algorithm development efforts



- **B-757 flight tests**

- joint with other WxAP tests
- primarily focus on convective turbulence
- joint data for post-flight correlation with
  - in-situ
  - radar measurements
- support lidar performance scaling and algorithm development efforts
- investigate scan strategy tradeoffs





# Transceiver Status

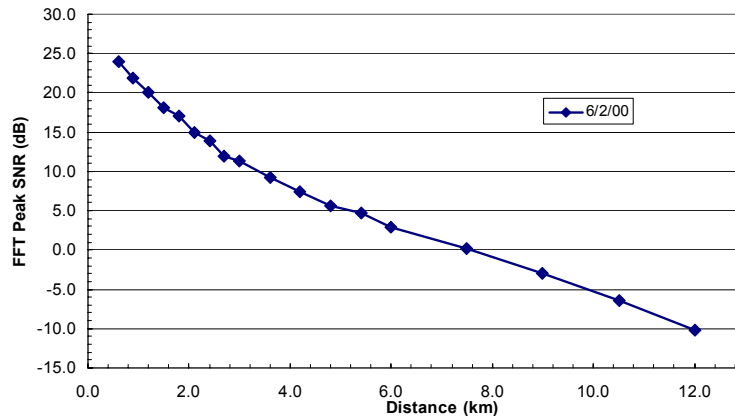


**Aviation Safety Program**

- **AFRL hardware delivered in March 2000**
  - **Specs after tune-up at CTI**
    - 2.0125  $\mu\text{m}$  wavelength
    - 9.3 mJ (out of telescope), 440 nsec pulse duration, 100 Hz PRF
    - 8 cm beam diameter, 10 cm aperture, internal telescope focused at 1.5-2.5 km
    - 20% small beam efficiency measured in June
    - horizontal path data show range performance to 10-12 km (Colorado data)

Sample Data Collected for Horizontal Path In Colorado

FFT Signal Strength vs. Distance for AFRL 6-2-00



AFRL System for Precision Air Drop

**Installed in C-130 Fuel Pod**

**NASA/ACLAIM System**

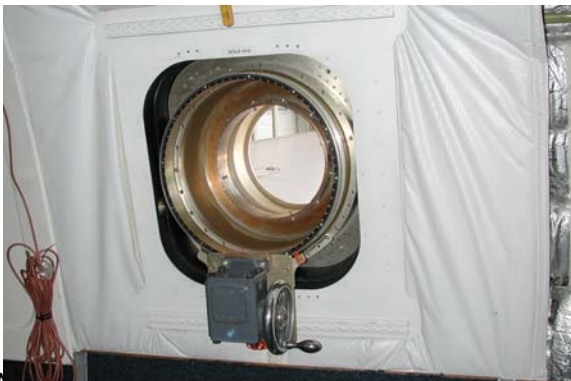


# DC-8 Flight Test Status



## Aviation Safety Program

- **DC-8 volcanic ash encounter**
  - engine replacement required
- **Initial flight window (FY00) dropped**
  - Air-Sci program cancelled
- **CAMEX DC-8 flights scheduled for August-September**
  - piggyback status
  - ~100 flight hours total



# DC-8 Lidar Flight Test Status/Plans



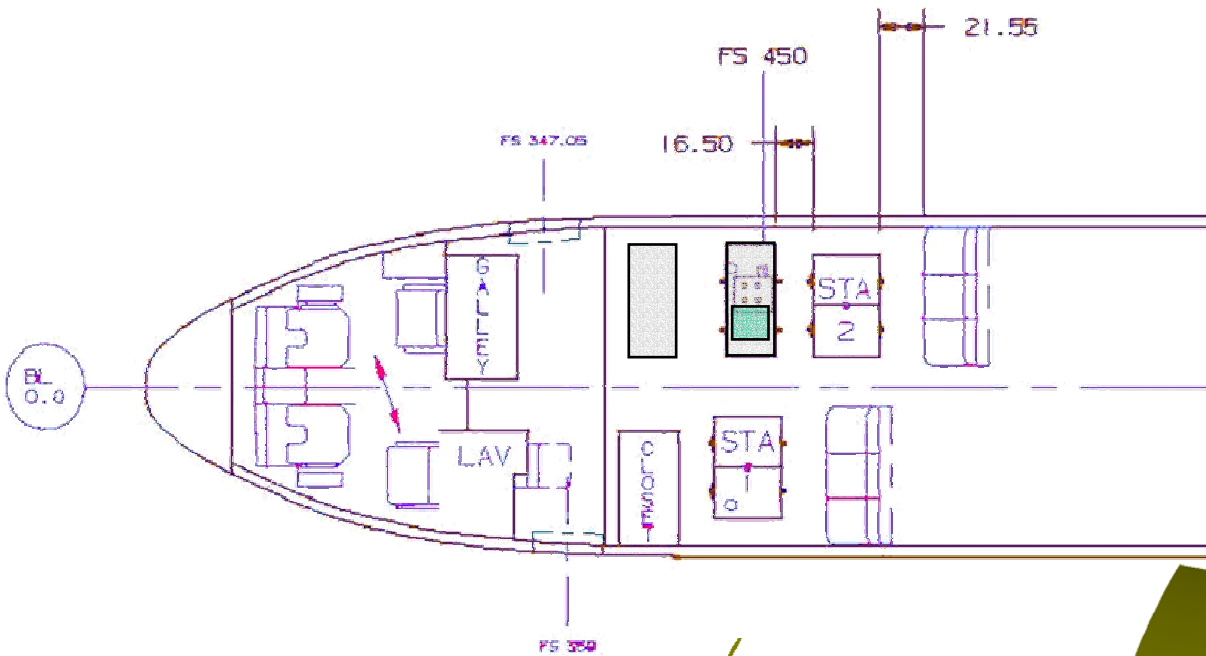
**Aviation Safety Program**

- **Forward-looking periscope installed at FS1015**
- **Integrated AFRL / NASA Lidar system undergoing ground testing at LaRC**
- **Instrument upload scheduled for July**
- **Flights anticipated in August-September**
  - piggyback on CAMEX includes in-situ turbulence and aerosol
- **Research focused on:**
  - cruise-condition flight data
  - correlation with atmospheric aerosols
  - correlation of wind shear measurements with other CAMEX measurements

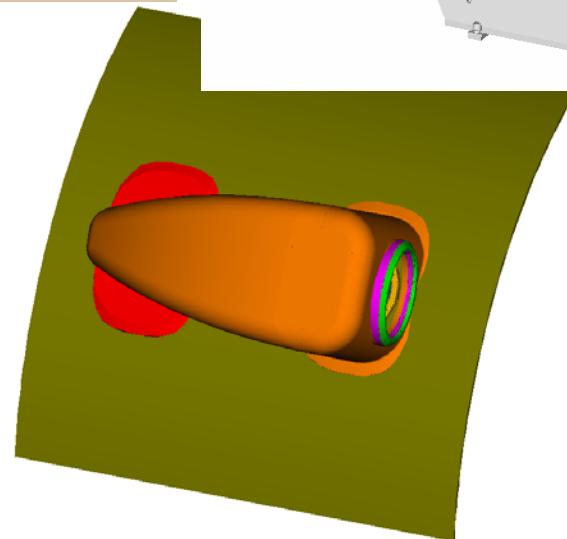
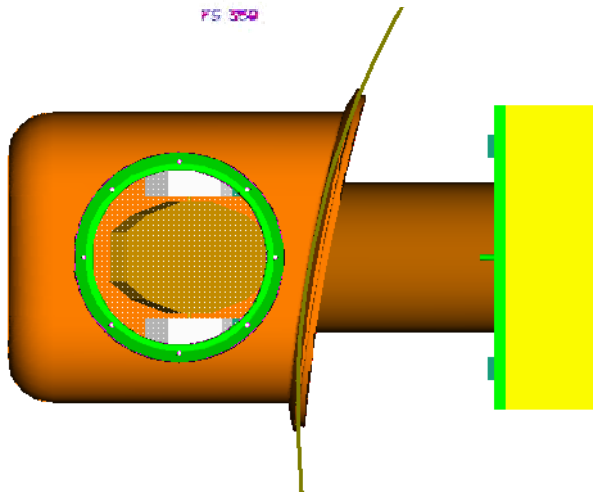
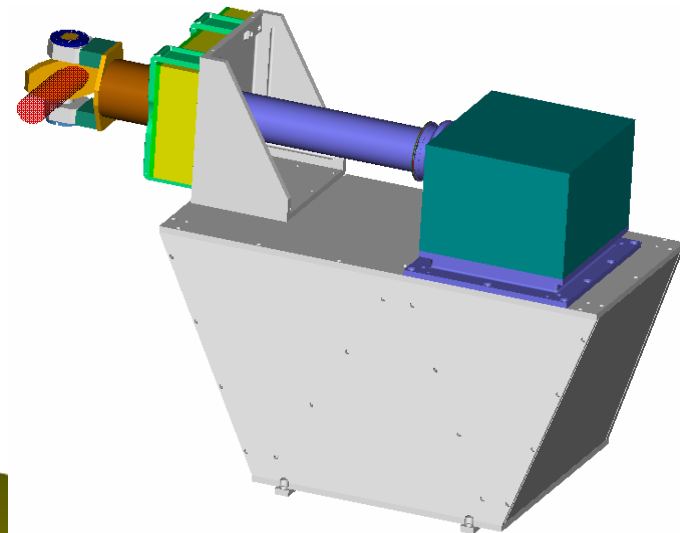
# B-757 LIDAR Instrument Layout



Aviation Safety Program



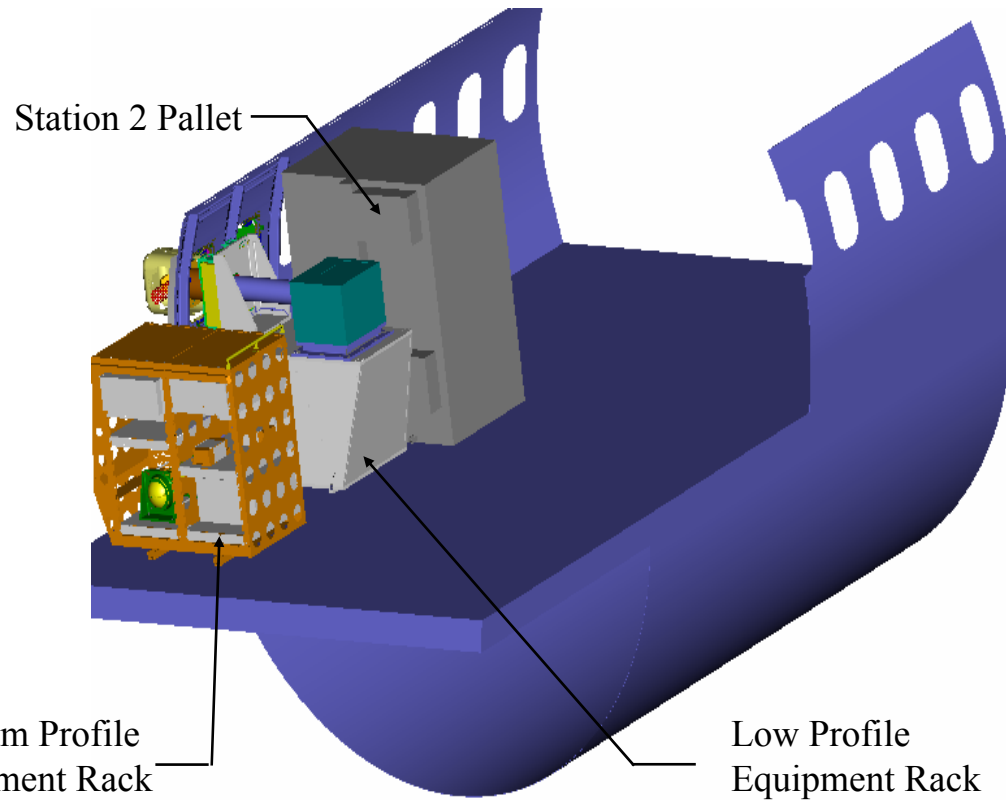
Rack Configuration



# B-757 LIDAR Instrument Layout



Aviation Safety Program





# B-757 Lidar Flight Test Status/Plans



## Aviation Safety Program

- **NASA Critical Design Review held in May 2001**
- **Design for forward-looking scanner installation approved for FS450**
- **Integrated AFRL / NASA scanning Lidar system undergoing ground testing at LaRC**
- **Flights anticipated in early CY02**
  - joint with Turbulence Radar and Turbulence In-Situ
- **Research focused on:**
  - scanning effects and strategies
  - synergism with radar
  - convectively-induced turbulence

# Lidar Algorithm Development Objective



**Aviation Safety Program**

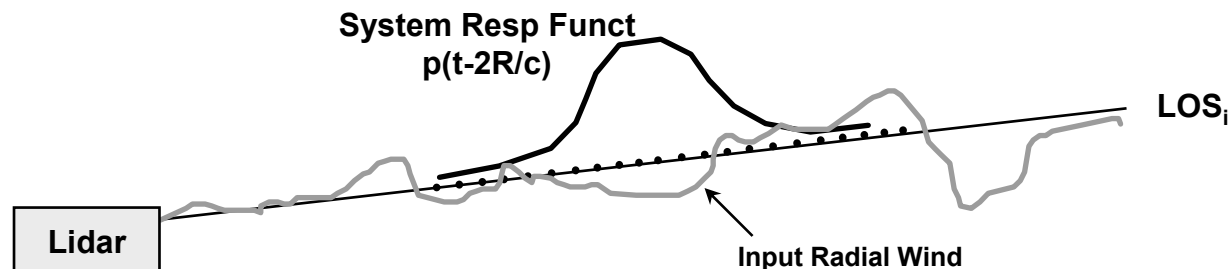
- **Develop reliable detection and discrimination algorithms for Doppler lidar prediction of turbulence hazard**
  - exploit understanding of unique aspects of lidar phenomenology
  - incorporate common aspects of radar developments

# Lidar Algorithm and Simulation: FY00-02 Approach and Plans



## Aviation Safety Program

- Maintain synergy with radar algorithm development
- Establish SNR requirements and averaging/resolution/performance trades for spectral width and structure function algorithms
- Establish link to hazard metric algorithm(s)
- Incorporate test cases in more sophisticated simulation
- Test on additional data sets (joint lidar/radar test data)
- Produce more robust performance predictions and feed back into algorithm development
  - false alarm mitigation



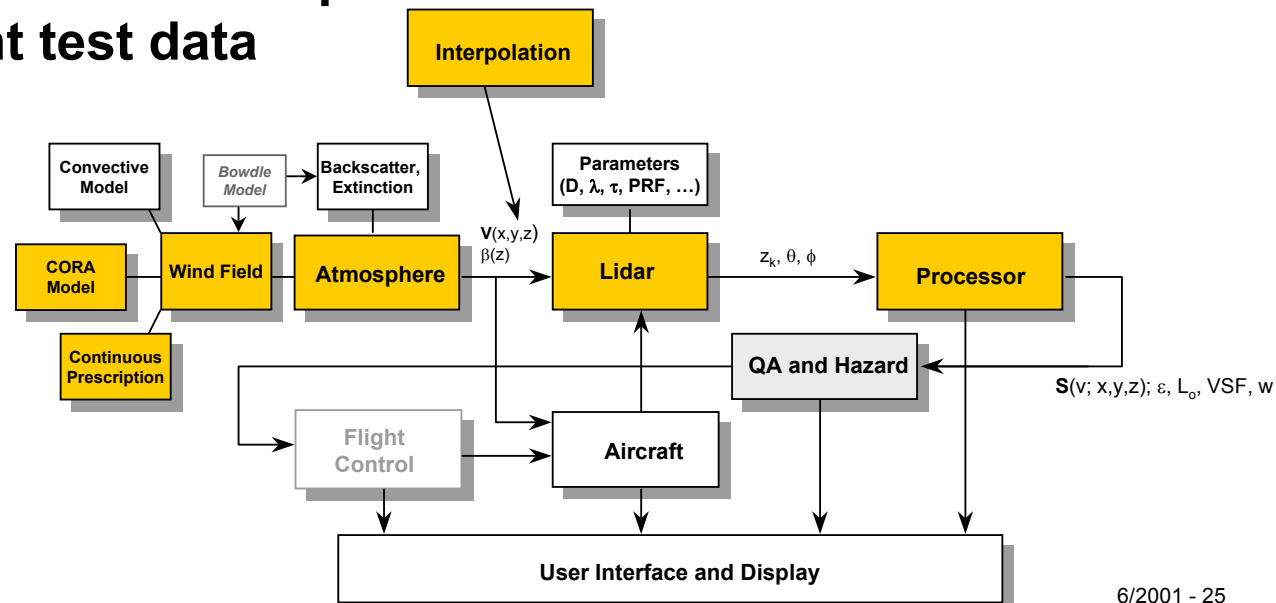


# Lidar Algorithm Development and Simulation: FY01/02 Activities



## Aviation Safety Program

- Focus on single line of sight algorithms/analyses and leverage existing tools
- Pursue structure function and spectral-width-based algorithms
  - small SNR regime: long range (longer warning times)
  - large SNR regime: correlation of vertical loading with longitudinal observations
  - investigate scan strategy impacts
- Develop preliminary performance predictions based on combination of simulated and flight test data
- Truth metrics initially limited (simulation using 2DOF a/c)

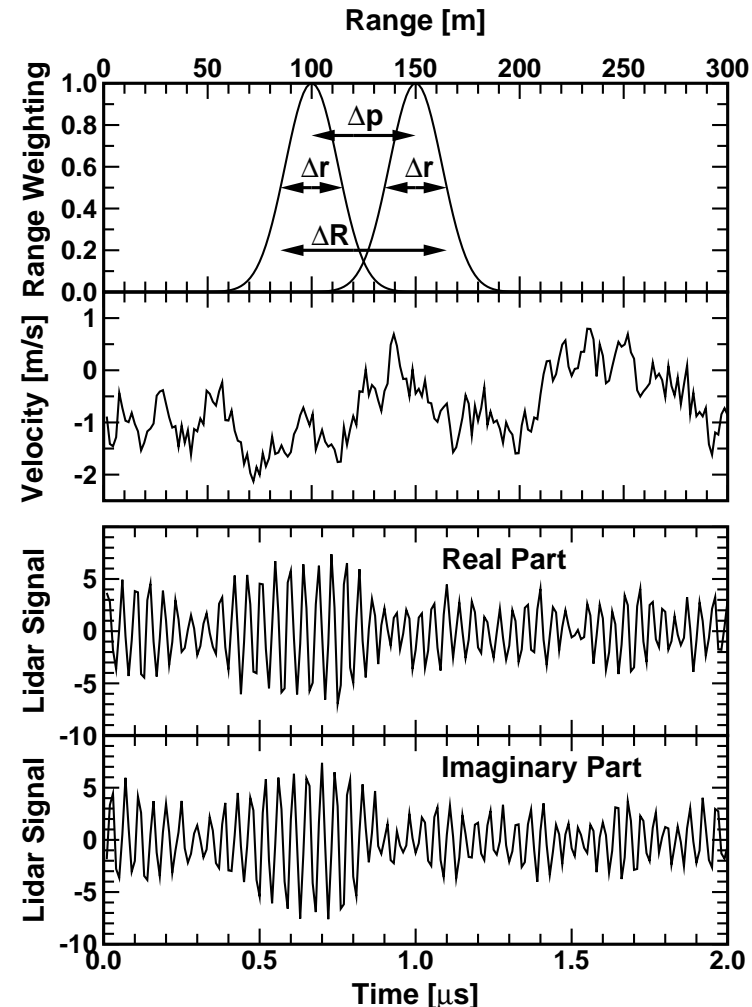


# Lidar Algorithm Development and Simulation: Leveraging



Aviation Safety Program

- **CIRES/NCAR:**
  - Space Lidar for NASA (SPARCLE)
  - extending detailed simulations
- **CTI**
  - simulation for wake vortex detection
  - existing real-time algorithms
- **Synergy with radar**
  - NCAR and RTI developments
- **Results in cost-effective development with near-term results**



# Lidar Summary



## Aviation Safety Program

- **Emphasis areas**
  - flight testing
  - algorithm development and associated performance analyses
- **Flight tests accomplished CY99-00**
  - NASA ACLAIM Electra flights
  - industry-funded B-720 flights
- **Flight tests planned for late CY01, early CY02**
  - DC-8 flights planned for August-September, piggy-back on CAMEX
  - B-757 flights in early CY02, joint with Turbulence Radar and In-Situ
- **Algorithm work highly leveraged**
  - NCAR and CTI developments
  - synergy with radar work (NCAR & RTI)
- **Parallel industry program to develop a clear air turbulence product**
  - focus is on cost reduction and reliability improvement

# Turbulence Lidar Development Status



*Aviation Safety Program*



# Reference Foils

# SUPPORTED MILESTONES

(Through FY 02 only; Excludes WINCOMM)



## Aviation Safety Program

### WxAP Level II

Initial AWIN Concept and  
Forward-Looking Turbulence  
Detection Flight Evaluation

Flight Demonstration of  
Forward-Looking Turbulence  
Warning System

National AWIN  
Capability

**FY 00**

**FY 01**

**FY 02**

### **AWIN**

### Level III

Software  
Demonstration

Initial AWIN Concept  
Flight Evaluation

Weather Products and  
Sensor Selection

Prototype Concept  
Flight Tests of National  
AWIN Capability

### **Turbulence**

### Level III

Flight Demo of  
Turbulence Detection  
Concept

Demonstrate  
Turbulence Detection  
System

Detection System  
Flight Test with AWIN

*In-Situ Algorithm Concepts  
Flight Evaluation*  
(L-IV milestone)

*Enhanced In-Situ Algorithm Flight  
Demo (uncoupled from AWIN)*  
(L-IV milestone)

Turbulence In-Situ  
Algorithm  
Demonstration

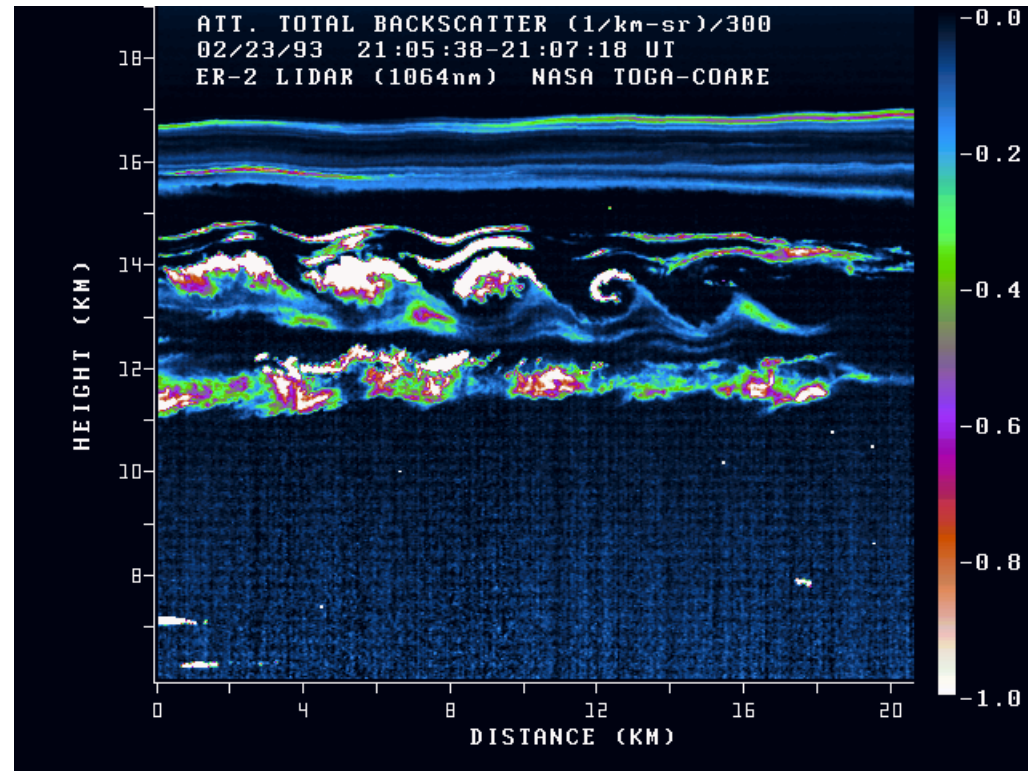
# Background



**Aviation Safety Program**

## • Turbulence Initiators

- **Convective Storms** (within and as far as 40 miles away from visible clouds in clear air)
- **Jet Stream** (at confluence of multiple streams and near boundaries)
- **Mountain Wave** (upward propagating from disturbances near the surface)



**Localized “events” like these are extremely difficult to reliably forecast**

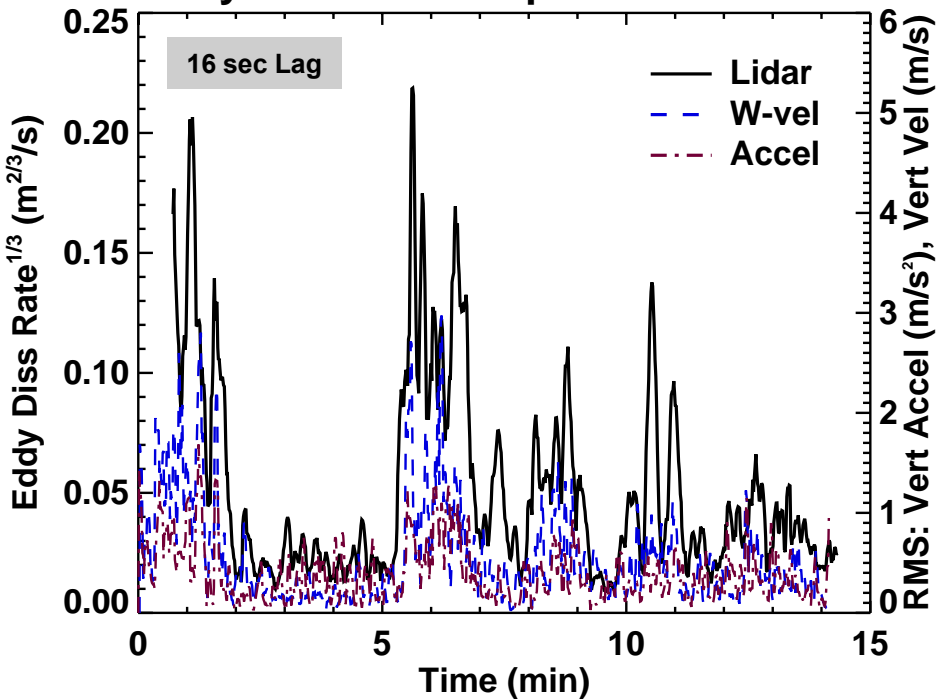
# Demonstration of Lidar Turbulence Detection

Good Correlation with Onboard Data out to 40 sec Lag (Flight 2)

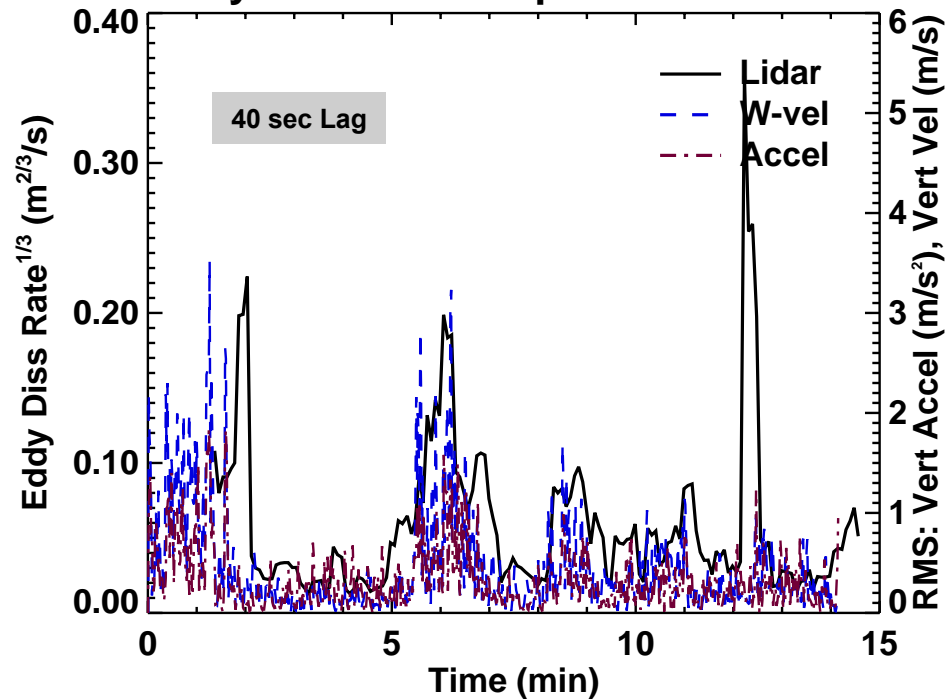


Aviation Safety Program

Eddy Diss Rate: Sep=293m @1963m



Eddy Diss Rate: Sep=270m @5068m



Time Evolution, Beam Pointing  
Jitter (A/C Pitch) Can Reduce  
Accuracy for Long Lags

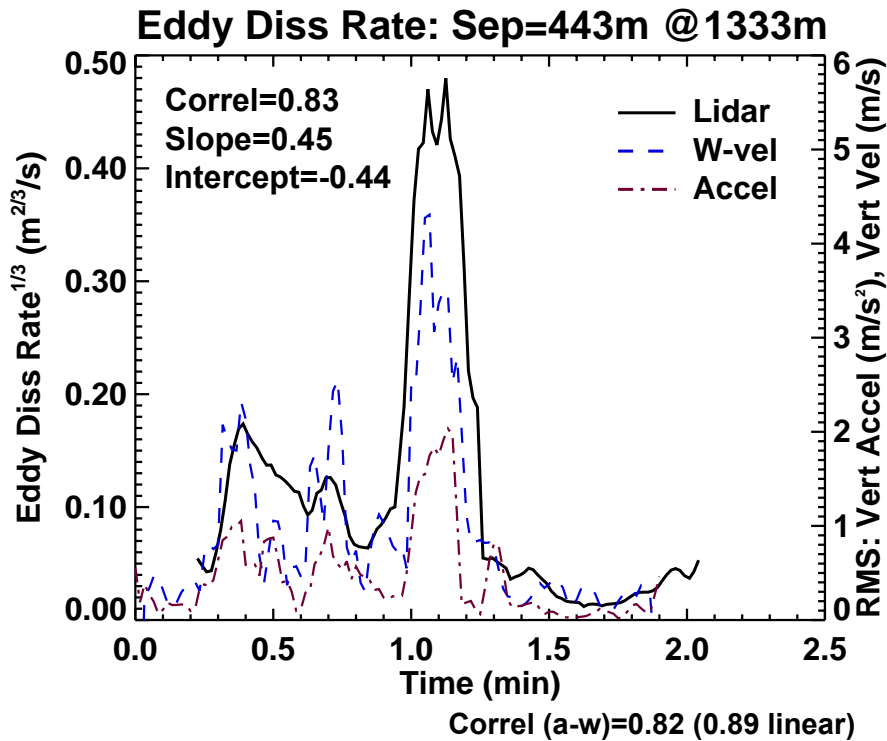


# Background: Demonstration of Lidar Turbulence Detection

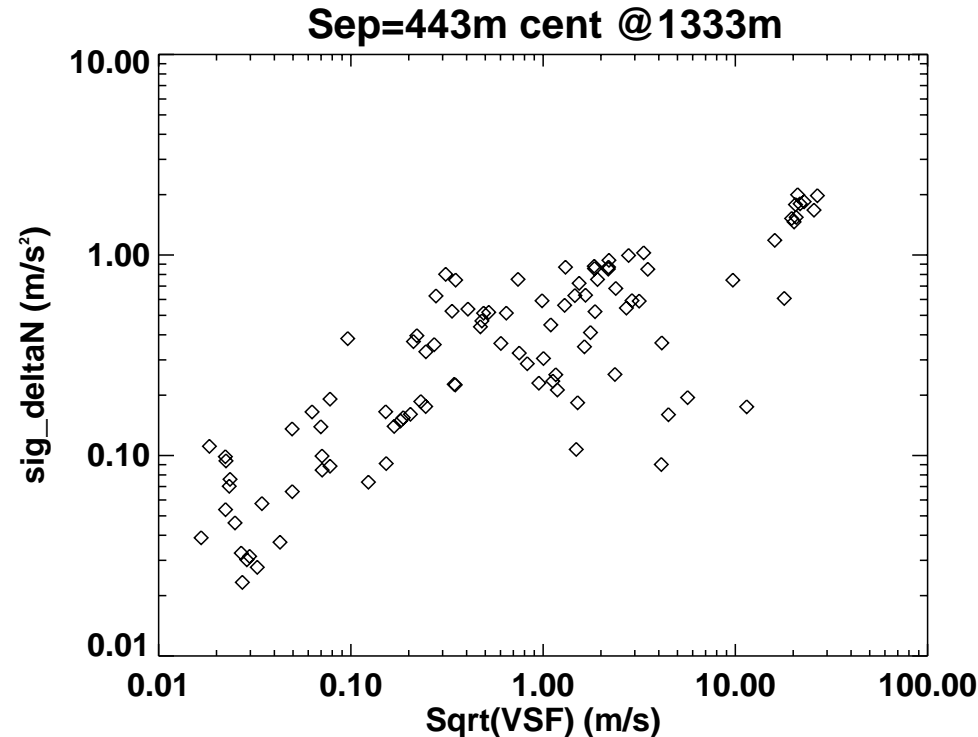
## Good Correlation with Onboard Data (Flight 2)



Aviation Safety Program



LidarFile=d:\raspprd\electra\d3261702.prd.los  
NavFile=d:\raspprd\electra\nav\802rf02\_1646\_1717.asc  
StartTime=1715:05, EndTime=1717:00 IntegWidth= 5.0sec



LidarFile=d:\raspprd\electra\d3261702.prd.los  
NavFile=d:\raspprd\electra\nav\802rf02\_1646\_1717.asc  
StartTime=1715:05, EndTime=1717:00 IntegWidth= 5.0sec

Correlation of 1.3 km lagged structure function about as good as that between rms acceleration and rms vertical velocity